# BIB's in ATLAS: Issues & Plans

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*for the ATLAS Background Working Group*

- **Introduction: scope & scale**
- **Expected impact of Beam-Induced Backgrounds on ATLAS performance**
- **Overview of background-monitoring instrumentation**
- **What feedback could ATLAS provide?**
- **What accelerator information might prove valuable?**
- **Special beam conditions**
- **Summary**

# Scope of this Presentation

- Detector-protection issues, beam-abort system & beam-accident scenarios
  - have so far received top priority in ATLAS
  - protocols are well advanced
  - instrumentation is installed
  - read-out electronics is in progress
  - communication & online-monitoring software in (various states of) progress

  *These topics are considered off-subject for this meeting.*

- Here, focus on ‘steady-state’ machine-induced backgrounds
  - under ‘stable beams’
  - Everything shown today
    - reflects the fact that in most areas the work is just starting,
    - is highly preliminary, and
    - some of it is most likely wrong!

# Introduction: the Scale of the Problem

- **ATLAS was designed to operate efficiently @ $\mathcal{L} \sim 10^{34}$ cm$^{-2}$ s$^{-1}$**
- **At nominal LHC luminosity, particle fluxes in/around ATLAS are dominated by**
  - **p-p interaction products in the Inner Detector, calorimeters and inner layers of the muon spectrometer**
  - **a 'sea' of n & $\gamma$'s (from high-$\eta$ impacts in the calorimeters & shielding) over most of the muon spectrometer**
- **Beam-halo & beam-gas rates (both from UX & distant) need to be assessed in comparison to the above rates and occupancies**
- **Backgrounds are likely to be worse at the beginning**
  - **relative to the actual luminosity (backgrounds scale much more slowly than $\mathcal{L}$ ), but also…**
  - **on an absolute scale (unconditioned vacuum system, stronger p halo)**
  - **In addition, the more open trigger may make the experiment more sensitive**
- **On the long term (nominal currents & $\mathcal{L}$ ), and in view of the simulation & operational uncertainties, it would be prudent to assume that BIB's could easily end up an order of magnitude larger than predicted today. This is <u>not</u> done in the numbers that follow!**

# Expected impact on ATLAS performance (I)

- **Inner Detector: $\mathcal{O}$ (500) charged particles (from pp) per Xing ($|\eta| < 3$)**
  - **in comparison, beam halo and beam-gas negligible in terms of dose & occupancy**
  - **track quality cuts eliminate most beam-gas and all halo "tracks" in ID (simulations by VT/AS)**

| Location | Charged-particle flux above 10 MeV (Hz/cm$^2$) |
|---|---|
| Pixel layer 0 | $40 \times 10^6$ |
| SCT layer 1 | $1.5 \times 10^6$ |
| SCT disk 9 | $10^6$ |
| TRT outer radius | $10^5$ |

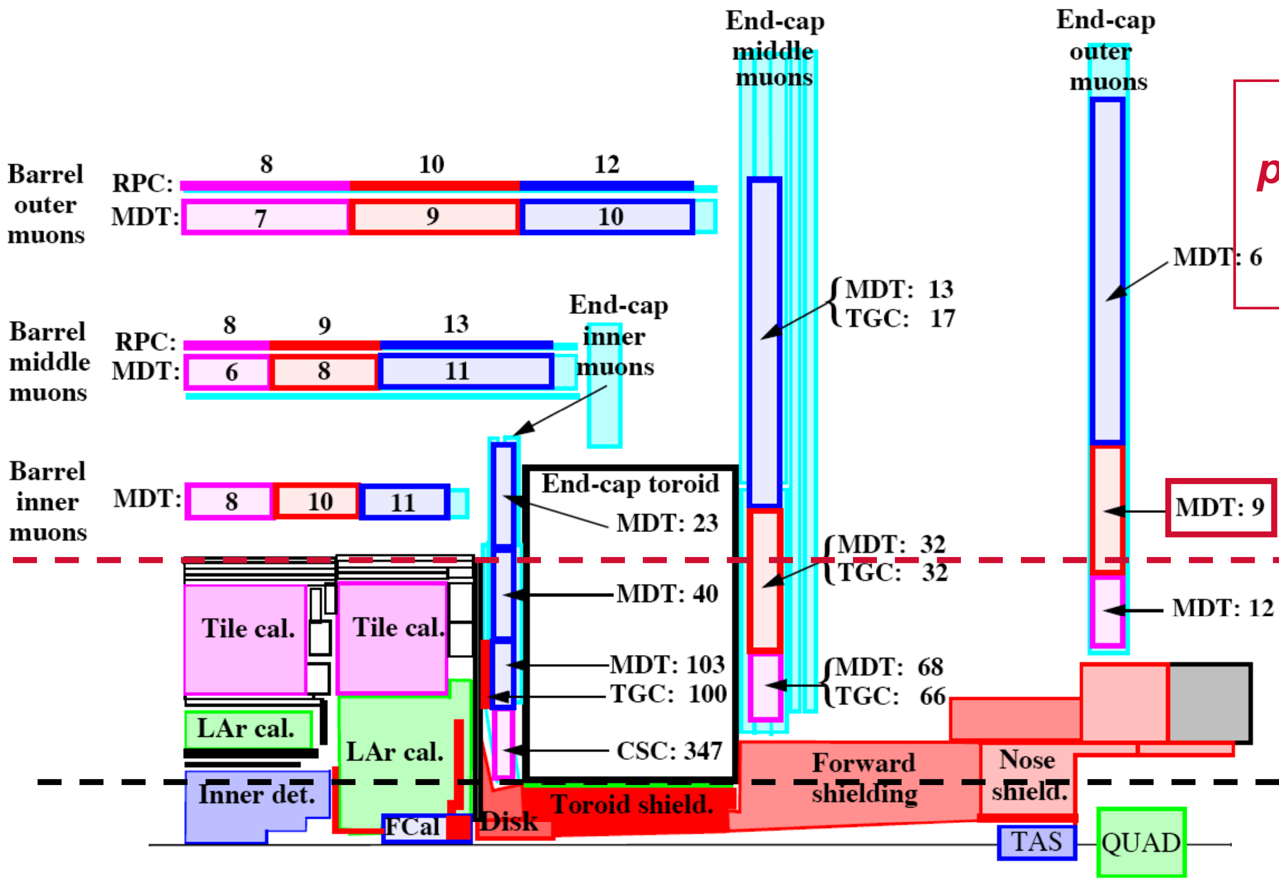
- **Calorimeters**
  - **In most of the liquid argon calorimeters the electronics noise is roughly equal to the pileup noise at $\mathcal{L} = 10^{34}$ cm$^{-2}$ s$^{-1}$**
  - **In order to be significant for event reconstruction, machine backgrounds must deposit energy density comparable to pileup events at $\mathcal{L} = 10^{34}$ cm$^{-2}$ s$^{-1}$**
  - **Tile calorimeter: no quantitative study yet, but expect conclusions similar to those in LAr**
  - **Forward calorimeters: at $\mathcal{L} = 10^{34}$ cm$^{-2}$ s$^{-1}$, pp interactions deposit about 7 TeV/crossing on each side**

# Expected impact on ATLAS performance (II)

- **Trigger: see M. Huhtinen's talk**
  - **Low beam-gas rates from UX imply these are not an issue**
  - **Uncertainty in halo (and distant beam-gas) rates imply that more study is warranted on events in the tail of the distribution, and on possible muon showering effects (see MH's talk)**
  - **Overall, no indications so far of any serious trigger worries from beam backgrounds**

- **Muon spectrometer**
  - **the fluxes of halo/beam-gas muons & of neutrons (from TCT) appears small compared to those from p-p interactions (next slide)**
    - **it might be wise to measure them at some stage (possible using a specially-configured forward-$\mu$ trigger; measurement may be limited to $|\eta| > 1.8$)**
  - **however, care needs to be exercized (at least initially) in turning on those chambers closest to the beam line**

***Average expected single-plane counting rates in Hz/cm²***
*from pp interactions at $10^{34}$ cm$^{-2}$ s$^{-1}$, for various regions in the muon spectrometer*




***Halo + distant beam-gas predictions ($p^{\mu}_T$ > 10 GeV/c), assuming TCT ~ 2 $10^6$/s , $\mathcal{L}$ ~ $10^{34}$***

*R ~ 4 m:*
*~ $10^{-3}$ - $10^{-2}$ $\mu$ cm$^{-2}$ s$^{-1}$*

*R ~ 1 m:*
*~ 0.5 - 1 $\mu$ cm$^{-2}$ s$^{-1}$*

*Even if the steady-state halo & beam gas muon rate were 10x higher than predicted, the impact on the muon spectrometer is not expected to be an issue.*

*A preliminary estimate (VT) of the n flux is ~ 0.8 n into the ATLAS cavern, per proton incident on the TCT - not an issue.*

# Overview of background monitoring instrumentation

- **Set 1: beam conditions facing the Inner Detector**
  - **Beam Conditions Monitor (BCM)**
  - **Beam Loss Monitors (BLM)**

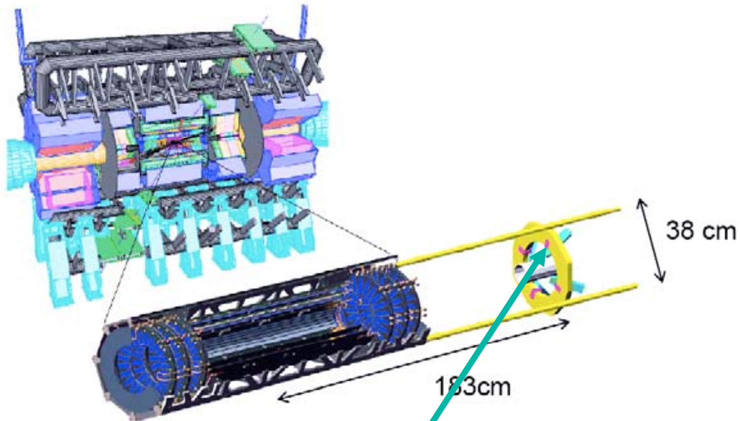
- **Set 2: ATLAS subdetectors as background monitors**
  - **Trigger-like observables**
  - **Occupancy-like observables**

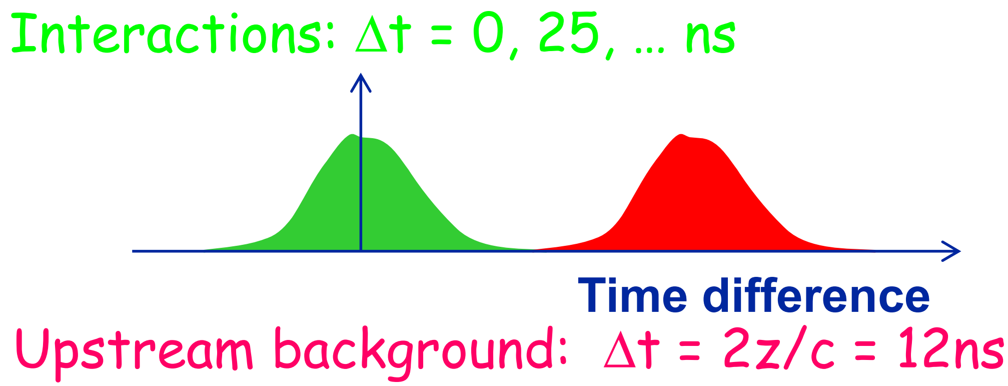
- **Set 3: analyze hadron / n / … els**
  - **Radiation M… unters)**
  - **N… pectrometer)**
  - 

**Unlikely to be relevant to today's discussion**

# Beam Conditions Monitor (BCM)

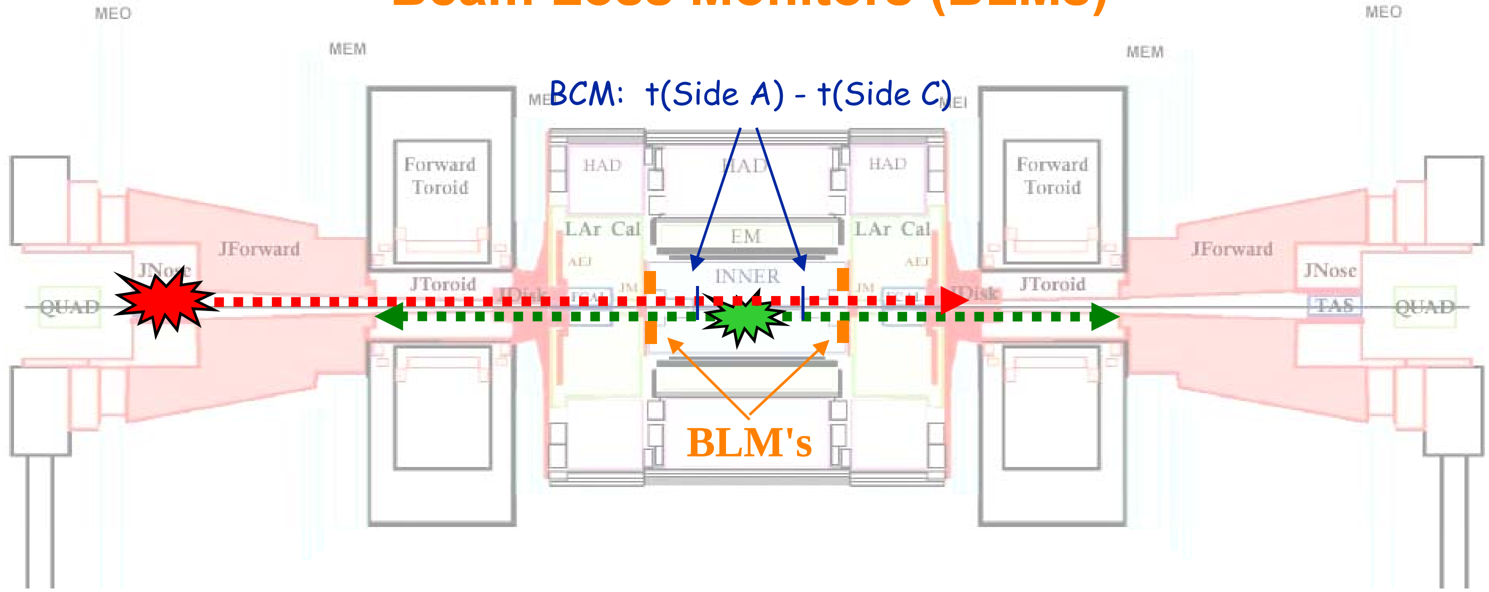
- **Distinguish collisions from background through time-of-flight measurement with detectors at either side of the IP**



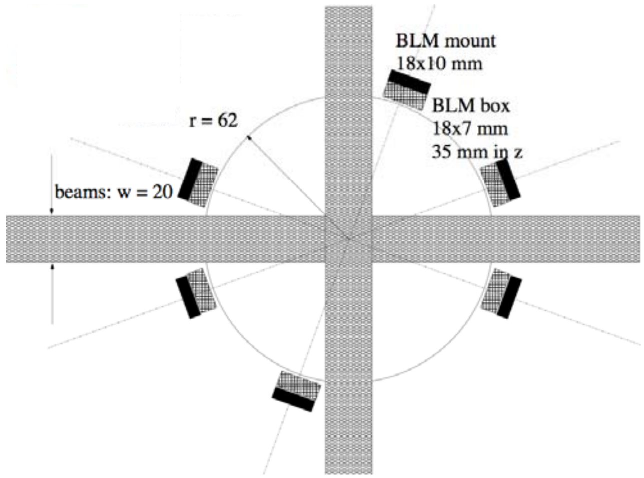




- **4 BCM stations on each side of the Pixel detector**
  - **mounted on Pixel support structure at z = +/- 183.8 cm and r = 6 cm**
- **Measure # particles /cm$^2$ for every bunch crossing (25ns)**
  - **fast, rad-hard 1cm$^2$ pCVD diamond sensor**
  - **fast elx (rise time ~ 1ns, width ~ 3ns, baseline restored in < 10ns)**
  - **FPGA-based control & monitoring**
    - **generates warning signals → DSS**
    - **generates 2 redundant beam-abort signals → ATLAS BIS**
    - **trigger signals to Central Trigger Processor (9) with hit pattern info**
    - **internal data buffer written to DCS after abort**

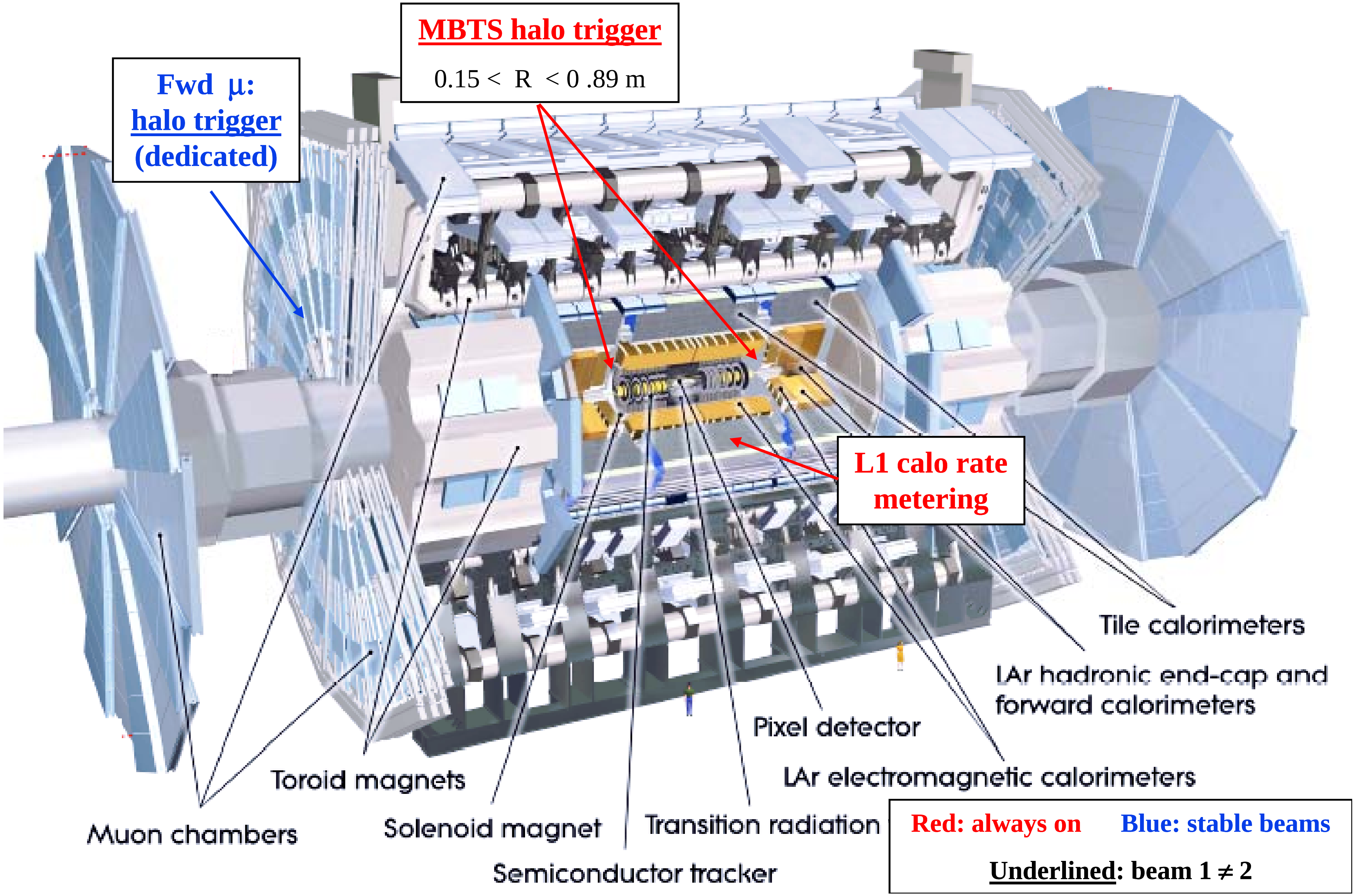
# Beam Loss Monitors (BLMs)




- Purpose: measure beam losses close to beam pipe by measuring the “DC” current in diamonds (similar systems used by BaBar & CDF )
  - Apply voltage to diamond and measure beam-induced current
    - Response time of the order of ~ 40µs (~ 1/2 machine turn)
  - 6 stations on each side at ID endplate close to beam pipe (R ~ 65 mm)
  - Will serve as a redundant system to BCM
    - Likely separate inputs to ATLAS BIS
  - Almost identical system in production for CMS, LHCb & Alice: will allow direct comparison of measurements between 4 LHC experiments

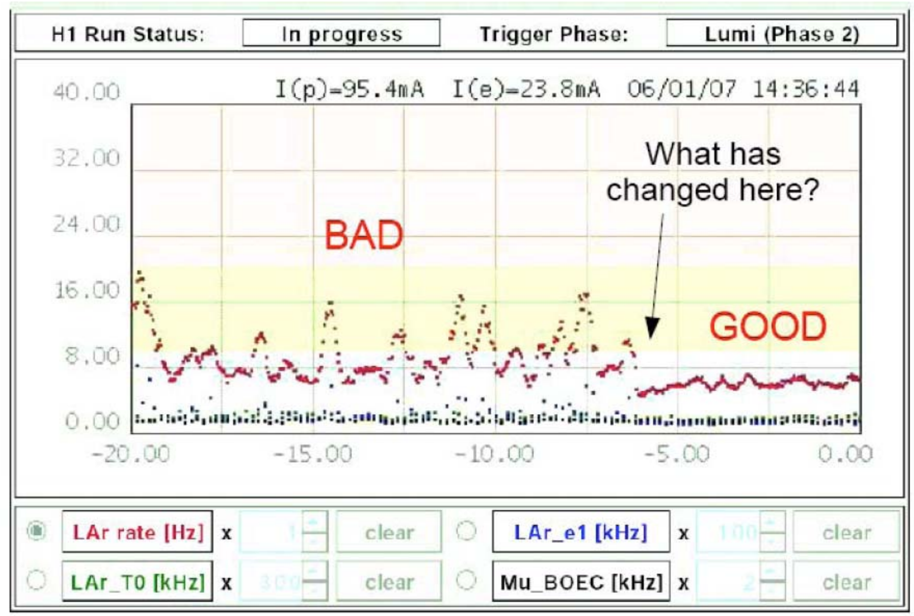


# ATLAS as a beam-background detector: "trigger" observables



# Level-1 calorimeter trigger: pre-processor rate metering

- L1Calo trigger will provide unbiased tower-by-tower rate monitoring
- full $\eta$–$\phi$ map covered with high granularity
- configurable energy and counting-interval threshold
- independent of further ATLAS trigger event selection and DAQ



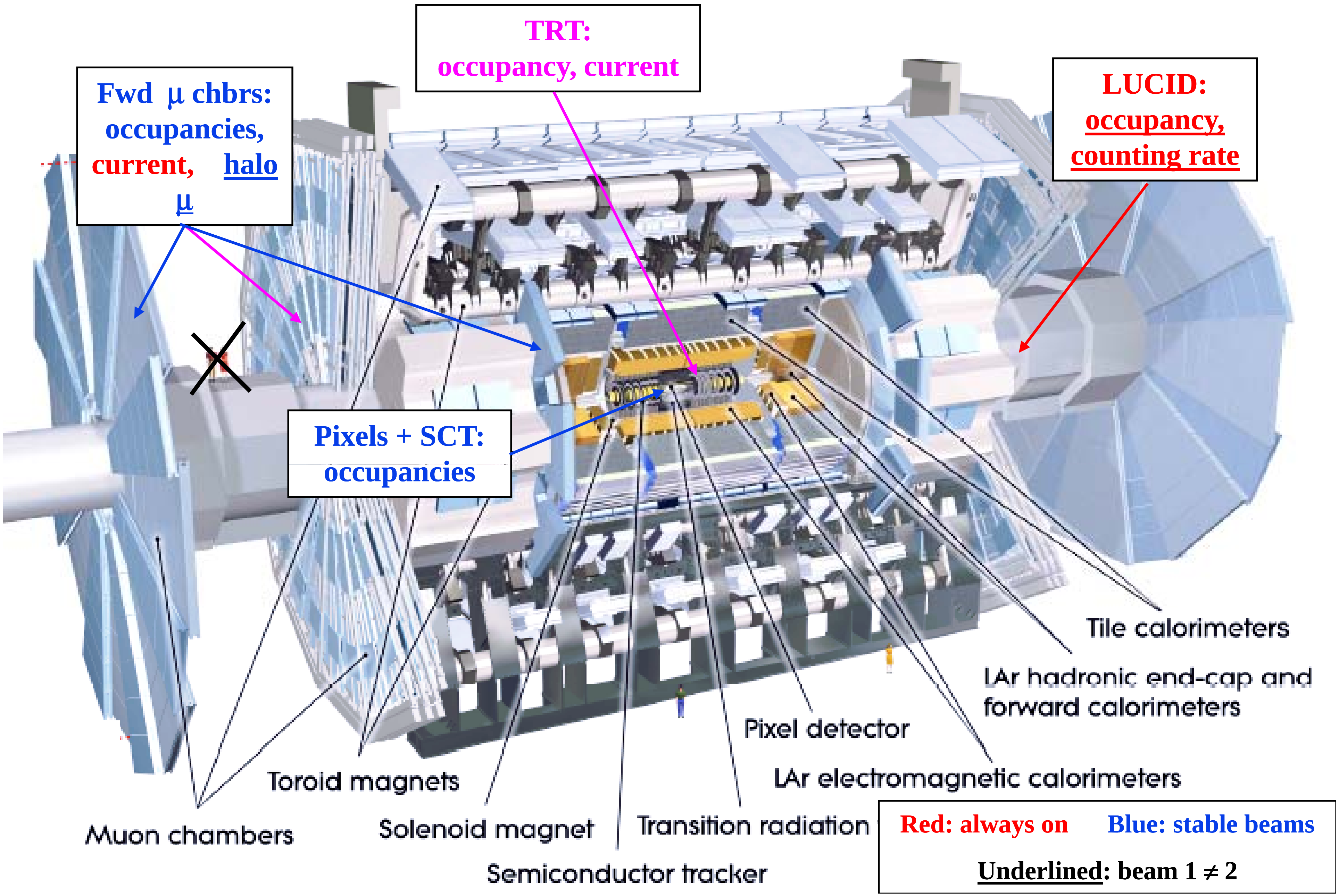

H1 LAr and muon trigger rates displayed in HERA control room for beam optimisation (halos)

→ diagnostics of calorimeter channels with abnormal input rates to the ATLAS Level-1 trigger

→ monitoring of beam conditions during physics data taking in ATLAS

→ interface between ATLAS and LHC control room to optimize beam conditions

# ATLAS as a beam-background detector: "occupancy" observables



# What information <u>could</u> ATLAS send to the CCC?

*Information sent to CCC clearly needs to be <u>concise</u> & <u>easy</u> to use; but only experience will tell what is useful & what isn't. The following is a menu of what could be made available: pick & choose!*

1. **Normalized background figures of merit (BFoM's)**
   - **present thinking: some combination of**
     - **BCM rate and/or pattern, MBTS halo-trigger rate, Lucid out-of-time rate**

       *(these distinguish beams 1 & 2 by timing; always on)*
     - **BLM dose rate, L1 calo rate metering**

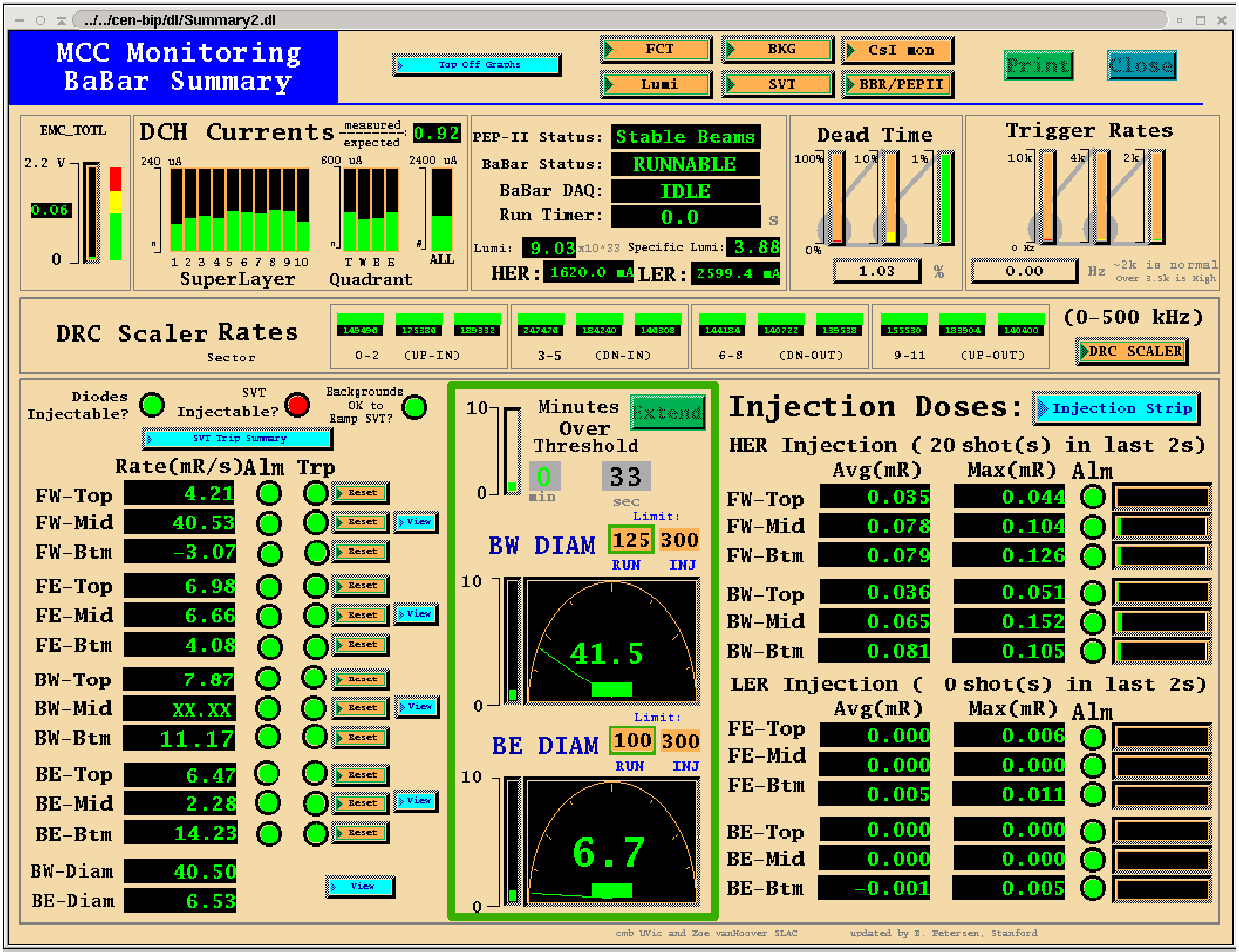
       *(no timing info, but beams 1 & 2 might be distinguishable by their spatial pattern; always on)*
   - **to be clarified**
     - **which of the above signal(s) or combinations ? (needs simulations)**
     - **how to subtract the $\mathcal{L}$ contribution ?**
     - **how many signals are desired? if only 2, have to choose between**
       - **beam 1 + beam 2 (1 signal ea.)**
       - **2 complementary signals that mix beams 1 & 2**
     - **normalisation: beam-current normalized? 'pain' normalized? different normalisation during injection, ramp/squeeze, setup, physics?**

***The choice & meaning of the BFoM's will unavoidably evolve with time - at least in ACR. What CCC 'sees' (after normalization) should remain operationally equivalent.***

# What information could ATLAS send to the CCC? (II)

2. **General info**
   - luminosity
   - position, orientation (?) & size of luminous region
3. **An ATLAS 'background status' or 'beam conditions' page?**
   - possible interface
     - Web page?
     - mirror of (well chosen) on-line monitoring display(s) ?
   - contents: summary background display (numbers?  thermometers?)
     - BCM & BLM (rates, patterns for beams 1, 2)
     - Trigger-like observables
       - Minimum-bias trigger scintillators (MBTS): halo rates in ID for beams 1, 2
       - L1 trigger: unbiased rate monitoring in calorimeters
       - muon-halo trigger & reconstruction using forward $\mu$ chambers (beams 1,2)
     - Occupancy-like observables
       - LUCID: background rate very close to the beam pipe (beams 1, 2)
       - current in TRT
       - forward $\mu$ chambers (beams 1, 2 ?)
       - occupancies in ID (pixel, TRT, SCT)
       - occupancies in forward muon chambers (beams 1, 2 ?)

# Example of background summary display (BaBar)



# What information could ATLAS send to the CCC? (III)

4. **Bunch-by-bunch information ( $\int$ - ed over many turns; scale: 0.5 -1 min)**
   - bunch timing wrt clock from BPTX pickups (beams 1, 2)
   - relative bunch luminosity $\mathcal{L}_b$ (or specific luminosity $\mathcal{L}_{sp} = \mathcal{L}_b / I_{b1} I_{b2}$)
     - from LUCID (2 ns time resolution, bunch-by-bunch counters exist)
   - backgrounds, separately for beams 1, 2
     - BCM
     - MBTS (via bunch-by-bunch monitoring of trigger inputs in level-1 central trigger processor )
     - LUCID (idem)
   - backgrounds (global)
     - L1 calo rate metering
     - ID and/or muon chamber occupancies?

   For both of these:
     - no 1-2 discrimination, except maybe through patterns
     - bunch-by-bunch capability to be confirmed

# What accelerator information might prove valuable to ATLAS?

## ❍ General machine parameters at point 1

*The list stored on the LEADE page: https://twiki.cern.ch/twiki/bin/view/Leade/WebHome*

| | |
|---|---|
| Total beam intensity | dip/acc/LHC/BeamIntensity/Total/* (Ring1 and 2) http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Individual bunch intensities | dip/acc/LHC/BeamIntensity/PerBunch/* (Ring1 and 2) http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Average 2D beam size | dip/acc/LHC/BeamSize/* (Ring1 and 2) http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Average bunch length | dip/acc/LHC/Class/Property/Device |
| Luminosity cdte mean | dip/acc/LHC/LuminosityAverage/* http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Luminosity cdte b-by-b | dip/acc/LHC/LuminosityPerBunch/* http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Luminosity Gas mean | dip/acc/LHC/LuminosityAverage/* http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Luminosity Gas b-by-b | dip/acc/LHC/LuminosityPerBunch/* http://bdidev1.cern.ch/bdisoft/development/BDI-Domains |
| Average Beam Loss | dip/acc/LHC/BLM/Avg50 |

| | |
|---|---|
| HOR & VER Positions | dip/acc/LHC/BPM/Q1 |
| HOR & VER Positions | dip/acc/LHC/BMP/Totem |
| HOR & VER Positions | dip/acc/LHC/BPM/Atlas |
| Total longitudinal distribution | dip/acc/LHC/LongitunalDistribution |
| Machine Mode | dip/acc/LHC/MachineMode accelerator modes encodi http://wwwpsco.cern.ch/private/timing/timing/Seq/tgm |
| Beam Mode | dip/acc/LHC/BeamMode beam modes encoding defin http://wwwpsco.cern.ch/private/timing/timing/Seq/tgm |
| Beam type | dip/acc/LHC/BeamType/* (Ring1 and 2) beam type en http://wwwpsco.cern.ch/private/timing/timing/Seq/tgm |
| Beam energy | dip/acc/LHC/BeamEnergy multiply by 120 to get MeV |
| Safe beam flags | dip/acc/LHC/LTIM/SafeBeam/* (Ring1 and 2) flags en http://wwwpsco.cern.ch/private/timing/timing/Seq/tgm |

*seems fairly complete. Some additional suggestions follow (next slide).*

# What accelerator information might prove valuable to ATLAS? (II)

- General machine parameters (additional)
  - beam lifetimes
  - beam positions & angles at IP: $(x, x', y', y')_{1,2}$ from beam orbit monitors
- Vacuum
  - pump/gauge readings in incoming straights
- Collimation & beam losses
  - jaw settings & beam-loss rates at
    - tertiary collimators!
    - betatron & momentum cleaning collimators (stage 1? stage 2?)
    - injection collimators?
    - [dump collimators?]
- Beam loss monitors (other than collimators) ?

*Time scale for all these updates (secs to mins?) will be determined by how quickly things change: tbd on a case-by-case basis*

*Don't be shy about sending us info you think is useful!*

# Undesirable beam conditions?

- **Rule-of-thumb:**
  - ***slow*** **time variations are *OK*, spikes & hiccups are BAD!**
  - **prefer $\mathcal{L}$ to be as uniform as possible, along the bunch train & over time, so that trigger thresholds remain optimum throughout and dead-time corrections are simpler**

- **How much is acceptable in terms of**
  - **bunch-to-bunch $\mathcal{L}$ variations: *20% ? (needs further study)***
  - **luminosity & background variations within a fill: *that's life…***
  - **fill-to-fill luminosity & background variations: *more constant = more convenience, fewer setup errors, smaller corrections***
  - **bad vacuum conditions in IR: *at least 1 order of magnitude compared to current predictions [LHC project report 783] at full $\mathcal{L}$***
  - **satellite bunches & particles between RF buckets**
    - **may affect baseline (pileup) subtraction**
    - **$\mathcal{L}$ contribution should be << systematic error on relative-$\mathcal{L}$ measurement (% level)**
    - ***few % of charge should be safe***

## Special beam conditions in early running

- **Unpaired bunches for background monitoring ?**
  **Preliminary answer:**
  - **proved useful in CDF ?**
  - **should be available in both beams (separate background contributions)**
  - **to be worked out:**
    - **timing details (minimum gap required, where in the bunch train)**
    - **how many, how often**
- **Displaced collisions**
  - **potentially useful for ID alignment with tracks**
    - **some (aka 'weak") deformation modes (e.g. global scale) cannot be identified/corrected using projective tracks, but can (in principle) be recovered using displaced vertices**
    - **preliminary studies show that events originating at 37.5 cm can be reconstructed with almost full efficiency**
    - **their effectiveness in improving the ID alignment remains to be quantified**
  - **1-bucket offset ($\Delta z$ = 37.5 cm) preferred (pixel barrel is ~ 77 cm long);**
    **12 h of running should suffice (limit is DAQ bandwidth, not $\mathcal{L}$ )**

# Areas where work is needed before first beams (a partial list…)

- Self-consistent, validated accelerator-background simulation (distant beam-gas + halo from tertiary collimators)

- Background simulations in ATLAS
  - complex simulation machinery now ready (A. Stradling, V. Talanov)
    - usable by all ATLAS subdetectors - but manpower needed!
    - needs reference input data set: $\mu$ & hadrons at z = 23 m scoring plane
  - top priority: "calibrate" the background monitors:
    - BCM rate, multiplicity & patterns
    - BLM & MBTS signatures

    against particle fluxes & danger levels in
    - pixels, SCT, TRT
    - innermost forward $\mu$ chambers
  - determine how useful background muons can be to align
    - the Inner Detector
    - the muon spectrometer

# Areas where work is needed before first beams (II)

- **Information transfer between ATLAS & LHC**
  - **top priority:**
    - **background info from ACR → CCC**
      - **choose signals, choose normalization**
    - **this requires the above-mentioned simulations**
  - **ACR: comprehensive & integrated set of background monitoring tools**
  - **both ways (ACR ⇔ CCC) : finalize/commission communication protocols**

- **Background monitoring instrumentation**
  - **tool needed to monitor the backgrounds…**
    - **at large radius in the $\mu$ spectrometer**
  - **implementation must be completed (path is known) for monitoring**
    - **very close to the beam pipe (LUCID)**
    - **close to the pixels (BCM)**
    - **over the ID (BLM's, MBTS)**
    - **in the calorimeter (L1 rate)**

# Conclusions

- Simulations suggest that beam-induced backgrounds should not be a major issue for ATLAS; reality, however, may decide otherwise - especially during early running
- A panoply of background monitors is available
  - sensitive to very different time scales (1 bunch Xing to 1 ring turn),
  - covering from the immediate vicinity of the beam pipe to the radius of the calorimeters, and in many cases always active (including during injection).
  - However the $\mu$ halo at large radius (R > 1 m) remains difficult/cumbersome to characterize experimentally.
- The definition, and the implementation, of normalized BFoM's still is at a very early stage. Progress requires
  - an agreed-upon set of machine simulations (exclusive rather than weighted)
  - identifying suficient manpower in ATLAS
- Preliminary proposals have been presented with respect to
  - information flow from LHC to ATLAS (& v-v)
  - special and/or undesirable beam conditions during early running

# Credits & acknowledgements

- **The material shown above is a modest attempt at summarizing the discussions that started two months ago in the ATLAS Background Working Group:**

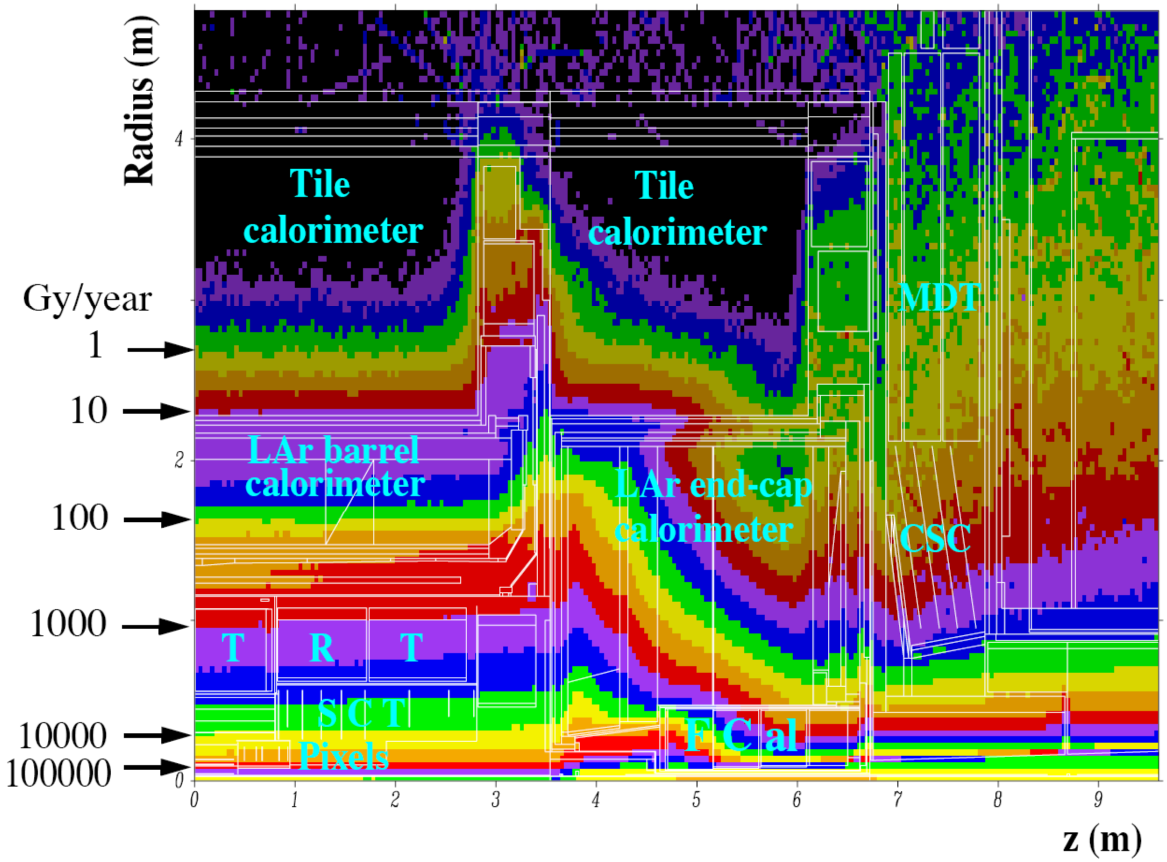
  *W. Bell, D. Berge, A. Brandt, K. Einsweiler, R. Goncalo, P. Grafstrom, V. Hedberg, T. Kawamoto, R. Kwee, T. Lecompte, G. Mikenberg, M. Mikuz, G. Mornacchi, T. Pauly, J. Rutherfoord, J. Schieck, M. Shupe, A. Stradling, V. Talanov, W. Trischuk, T. Wengler, S. Wenig, and M. Wessels.*

  *N. Ellis, M. Huhtinen, J. Schieck, and C. Young also contributed directly to this presentation.*

- **There was no way, in the time imparted, to do justice to the efforts of the teams - and of the individuals - who built, simulated, tested, installed and commissioned the various components of the ATLAS background-related instrumentation (detector protection system, BIS, BCM, BLMs, radiation & dose monitors, MBTS,…)**

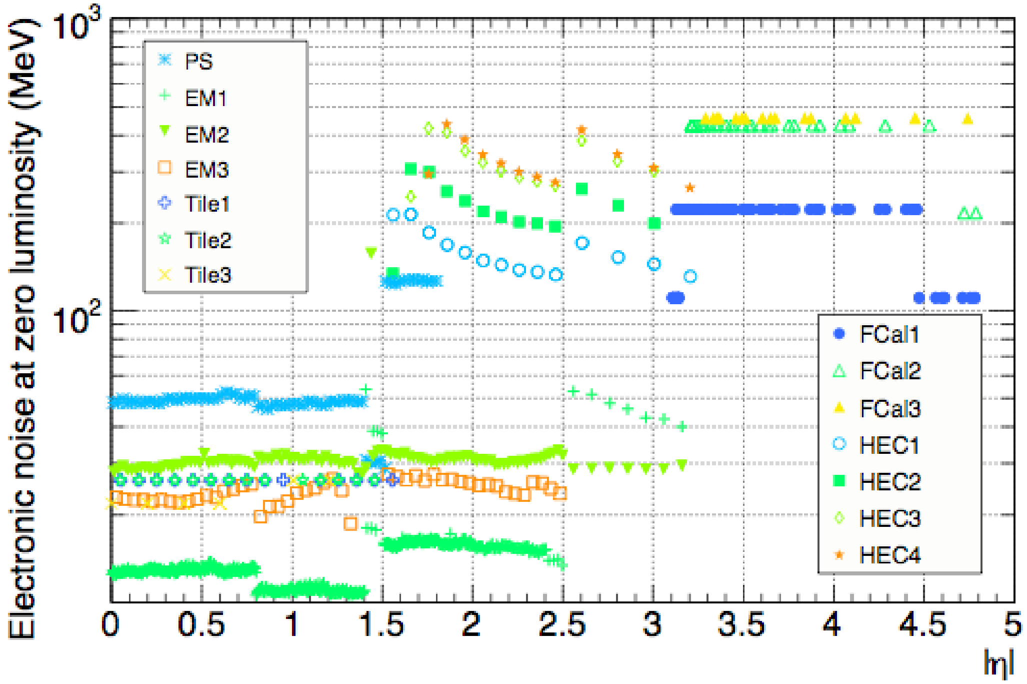
# Backup slides

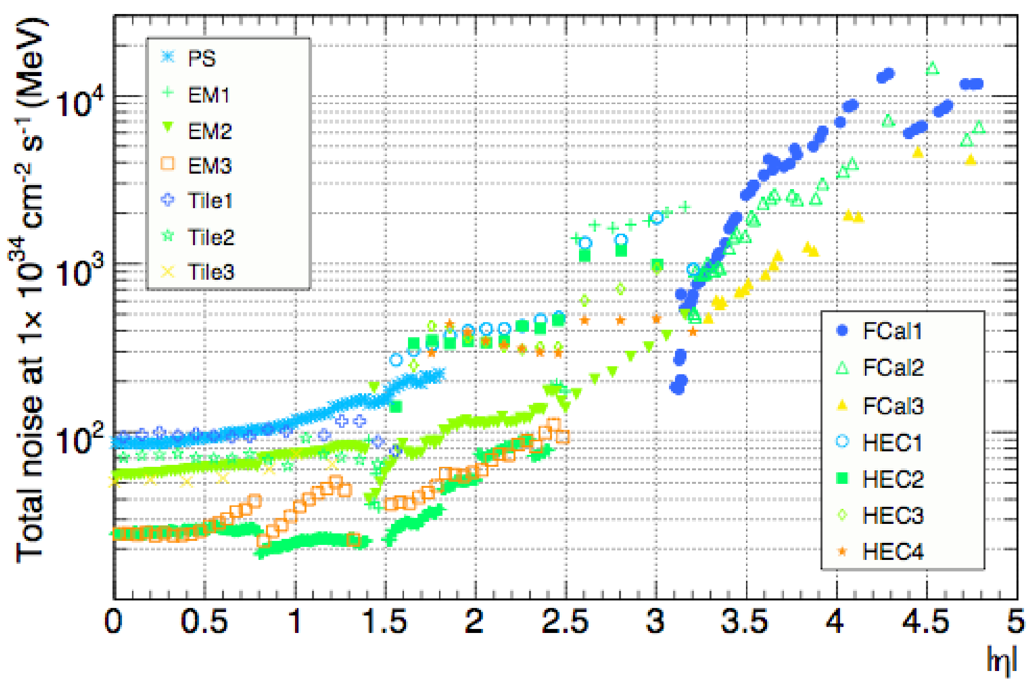
# Expected dose distribution in ATLAS




***Total ionising dose per year***
*($\mathcal{L}$ = $10^{34}$ $cm^{-2}s^{-1}$) calculated by GCALOR in one quarter of the central part of the detector. The locations of the inner detector sub-systems, of the different calorimeters and of the inner end-cap muon stations are indicated. The scale on the left gives the integrated dose per year corresponding to the various isolines.*

# Noise/channel in ATLAS calorimeters



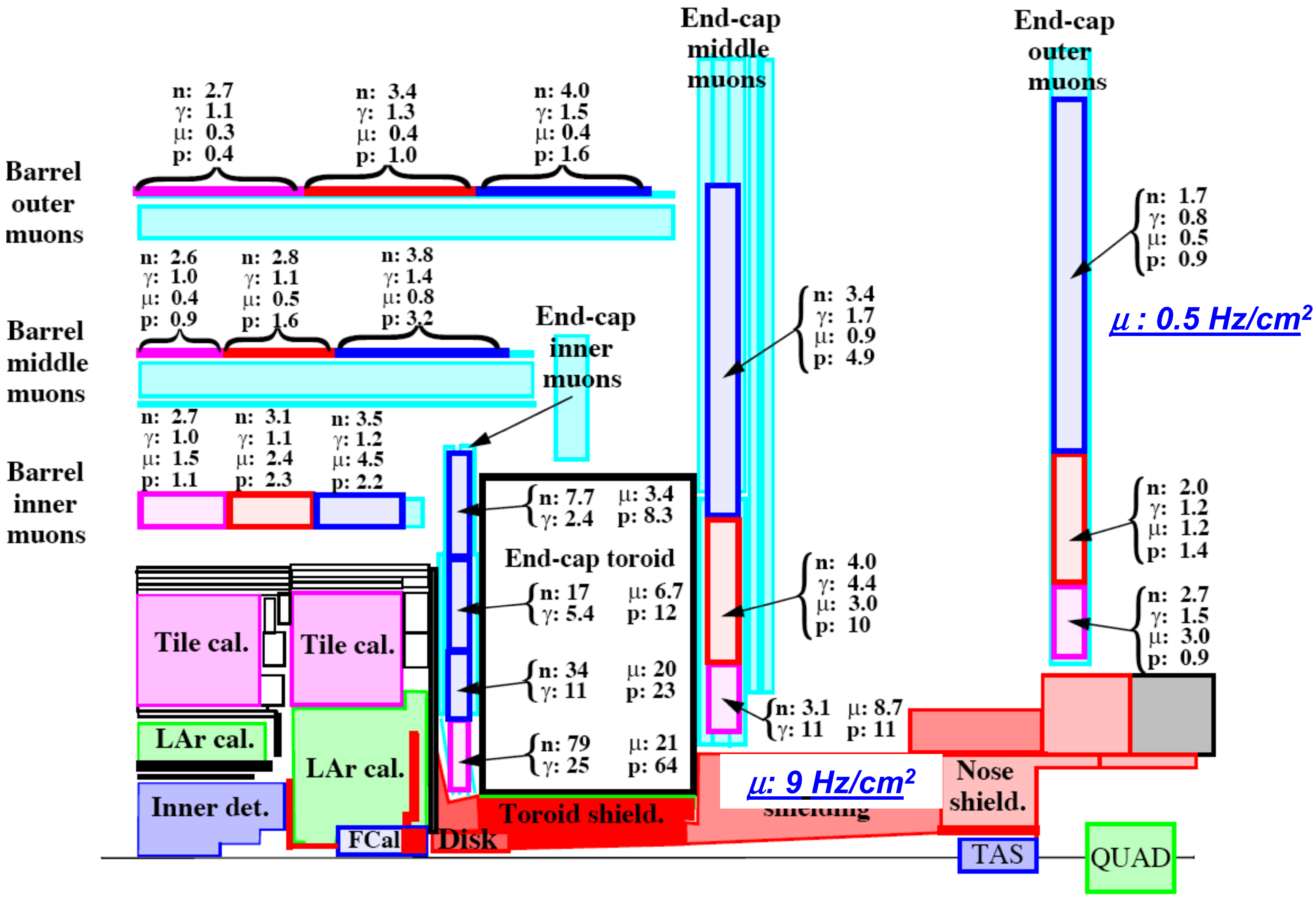




*W. Kozanecki*

**Particle fluxes from pp interactions, in the various muon stations at $\mathcal{L}$ = $10^{34}$ cm$^{-2}$ s$^{-1}$**

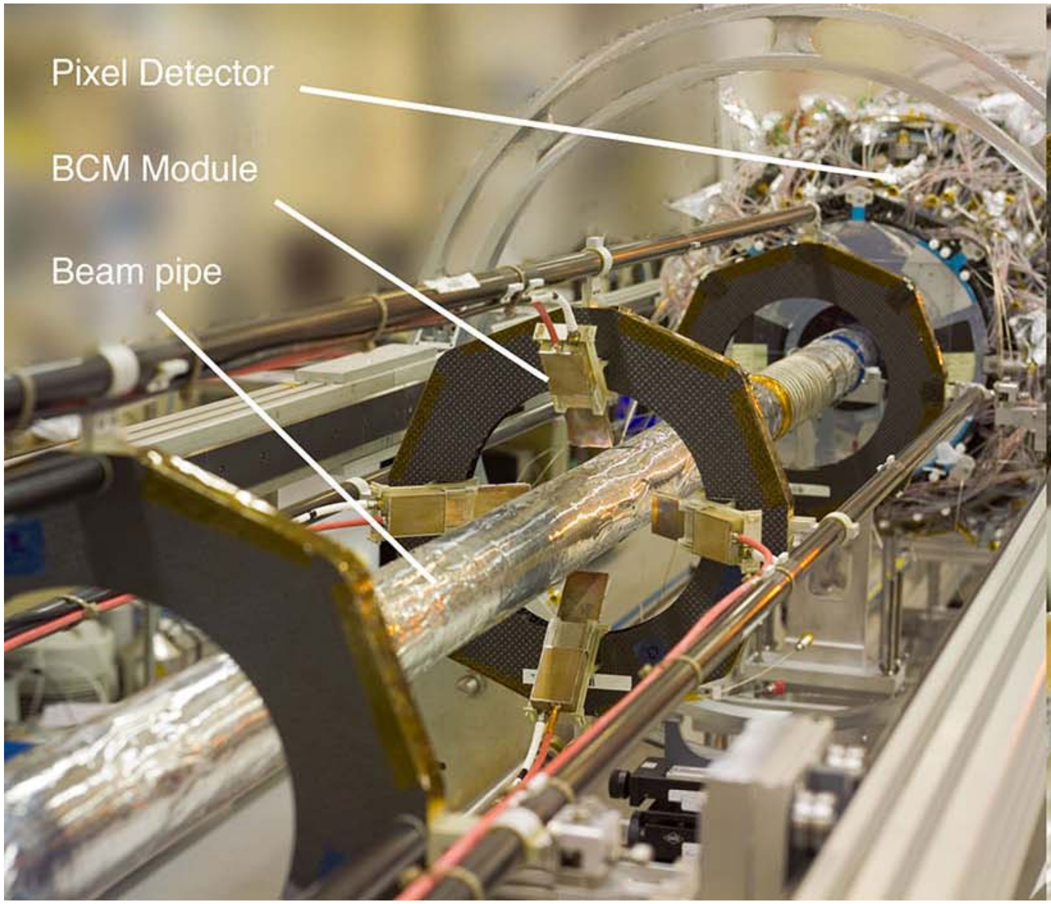
*as predicted by GCALOR.*

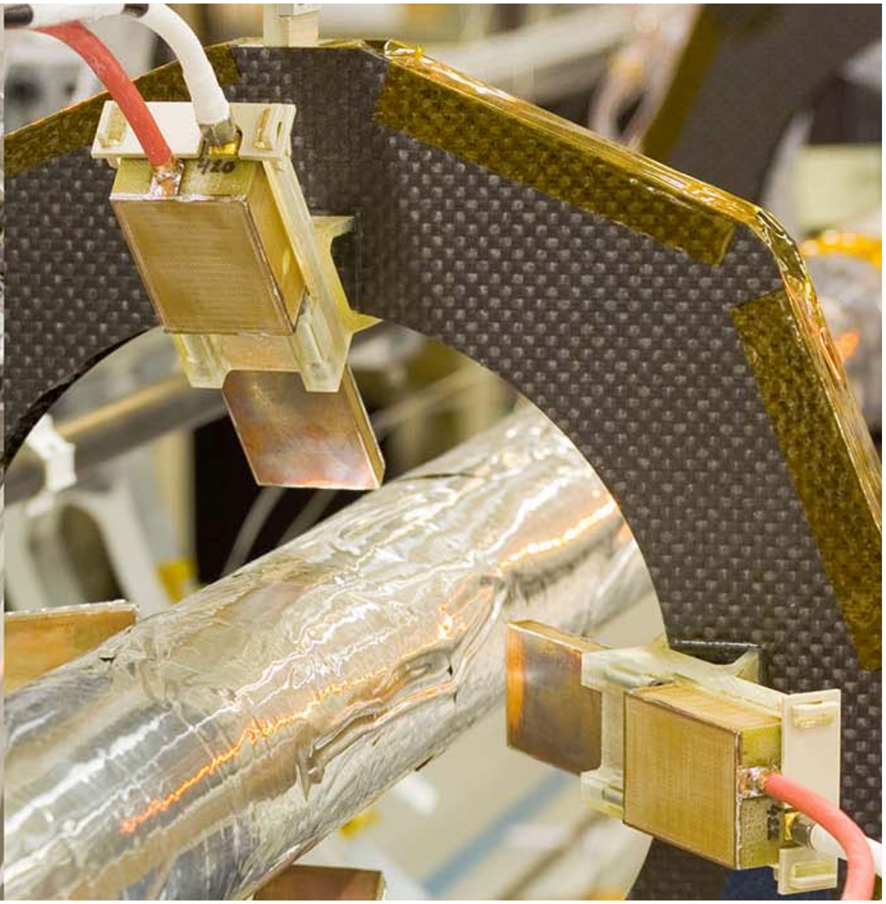
*The neutron & photon fluxes are in kHz/cm$^2$, the muon & proton fluxes in Hz/cm$^2$.*



# The BCM is installed in ATLAS

- 4 BCM stations on each side of the Pixel detector
  - Mounted on Pixel support structure at z = +/- 183.8 cm and r = 5.5 cm
  - Each station: 1cm$^2$ detector element + Front-end analog readout



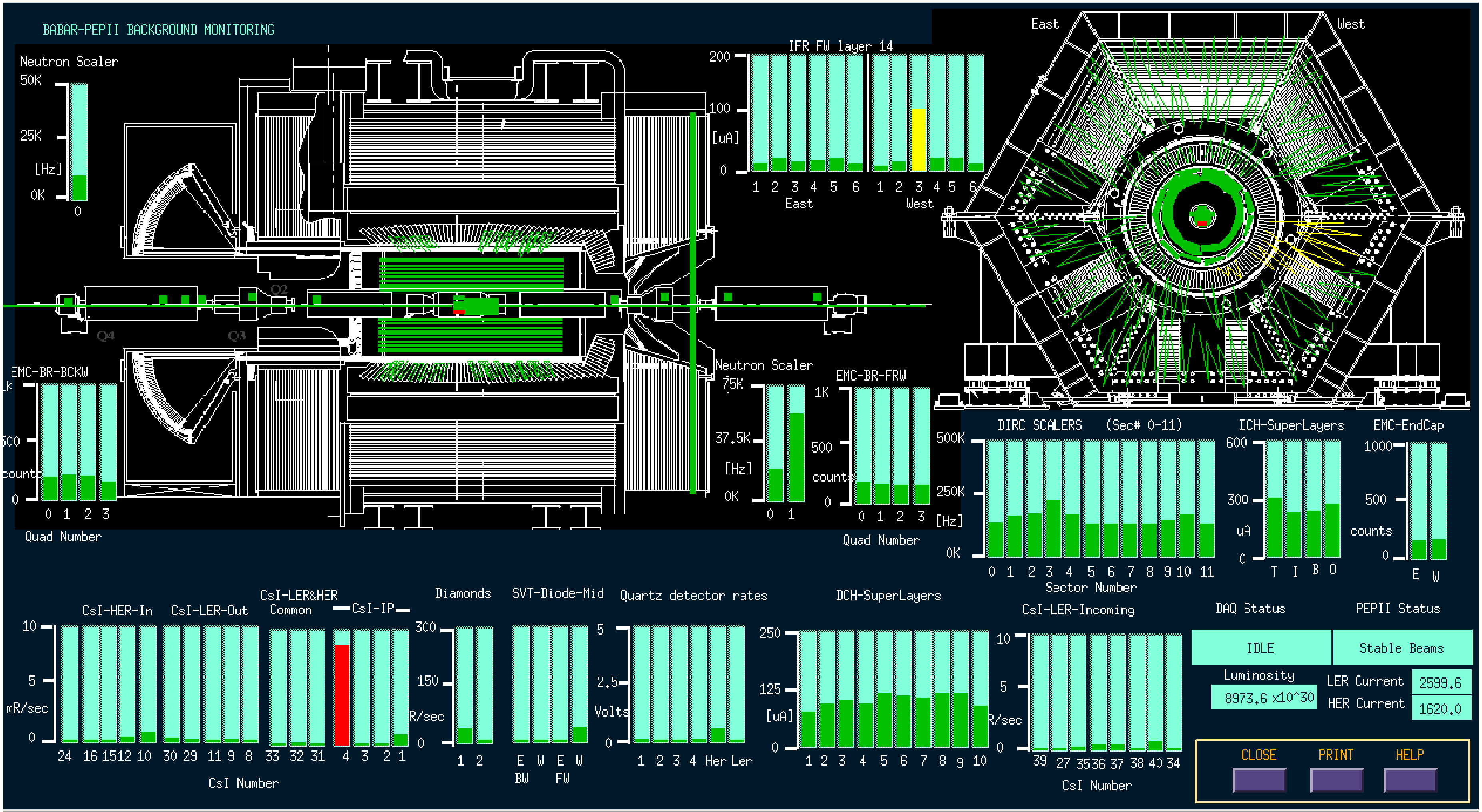



# Trigger-like background observables from ATLAS: comments

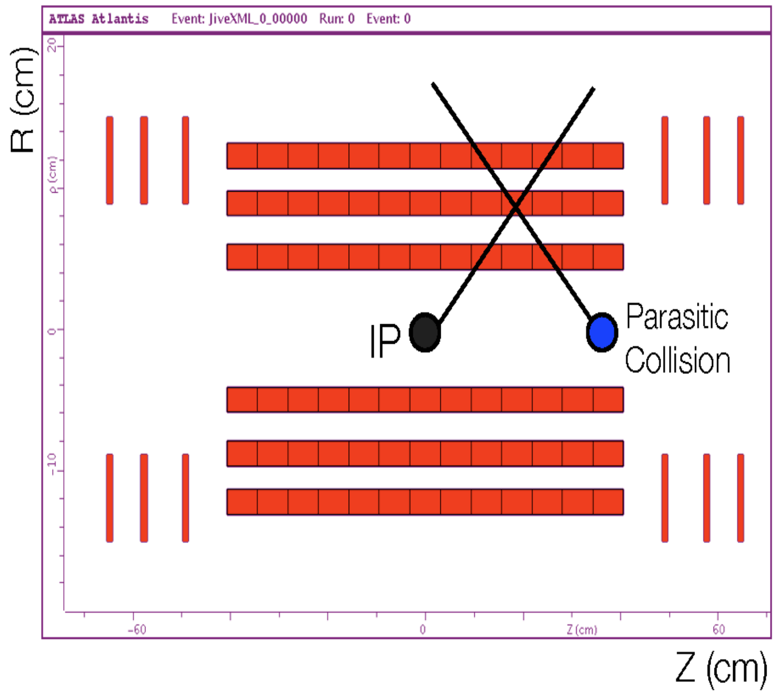
- **MBTS**
  - **halo trigger relatively easy to impelement (may require some NIM elx)**
    - **distinguishes muons from beam 1 and from beam 2 through coincidence timing**
  - **timing distribution could be made available**

- **Forward-$\mu$ halo trigger:**
  - **on the outgoing side: "easy" (although a dedicated configuration, incompatible with standard running)**
  - **two-side trigger (A-C) <u>may</u> be possible (no consensus…), but hard & invasive**

# Example of detector background display



# Displaced Collisions for Alignment




Tracks from displaced collisions break degeneracy

- **some systematic deformations of ID leave $\chi^2$ from tracks from IP unchanged**
  - **e.g. inflation along the beam pipe**
  - **no sensitivity for track-based alignment**
- **different track topology help to gain important additional information**